

We claim:

1. A method of indirect very long instruction word (VLIW) instruction memory (VIM) allocation comprising the steps of:

- identifying a plurality of VLIW instructions in an input source program;
- 5 determining a lifetime of each of said plurality of VLIW instructions; and
- allocating VIM based on the lifetime of each of said plurality of VLIW instructions.

2. The method of claim 1 wherein the step of determining the lifetime of each of said plurality of VLIW instructions further comprises the steps of:

- determining a control flow graph for the input source program containing said 10 plurality of VLIW instructions;
- determining a VLIW flow graph for said plurality of VLIW instructions; and
- determining VLIW interference.

3. The method of claim 2 wherein the step of determining the VLIW flow graph further comprises the step of:

- 15 solving VLIW flow equations.

4. The method of claim 2 wherein the control flow graph includes:

- a plurality of nodes which correspond to basic blocks of the VLIW instructions; and
- a plurality of edges, wherein each edge corresponds to a jump or a call from a given basic block to another basic block.

5. The method of claim 4 wherein the flow control graph at each of said plurality 20 of nodes includes:

- at least one VLIW instruction defined by the node; and
- at least one VLIW instruction used by the node.

6. The method of claim 5 further comprising the step of:

25 determining live-in sets and live-out sets for each of said plurality of nodes.

7. The method of claim 6 wherein the VLIW flow graph comprises the control flow graph and the live-in sets and live-out sets for each of said plurality of nodes.

8. The method of claim 7 wherein the step of allocating VIM further includes the step of:

30 determining an interference graph in which every node of the interference graph corresponds to one of said plurality of VLIW instructions.

9. The method of claim 8 wherein the VIM comprises a plurality of VIM lines, and the step of determining an interference graph further comprises the steps:

inserting an undirected edge into the interference graph between two VLIW nodes if the two VLIW instructions belong to a live-out set of the same node of the VLIW flow graph; and

coloring the interference graph nodes such that adjacent interference nodes are  
 5 colored in different colors and each color corresponds to a different VIM line.

10. The method of claim 1 wherein the lifetime of a VLIW instruction is a time interval extending from when said VLIW is defined by a load VLIW instruction to when said VLIW is last executed by an execute VLIW instruction.

11. The method of claim 1 further comprising the step of:  
 10 shortening the life of a particular VLIW by placing an initialization LV statement adjacently prior to the use of its corresponding XV statement.

12. The method of claim 1 further comprising the step of:  
 merging two non-overlapping VLIWs to share a common VIM line only when  
 15 colorability of a resulting VLIW interference graph does not worsen as a result of said merging.

13. The method of claim 1 further comprising the step of:  
 utilizing a coalescing heuristic to reduce VIM requirements of a program.

14. The method of claim 13 wherein said step of utilizing a coalescing heuristic results in a coalesced VIM address holding two or more of said plurality of VLIW  
 20 instructions.

15. A method of optimizing the execution time of a user program by reducing redundant loads of very long instruction word (VLIW) instruction memory (VIM) comprising the steps of:

selecting a load VIM (LV) instruction in a current node; and  
 25 placing the LV instruction in a new node which is closer to a program start node if an execution frequency of the new node is lower than an execution frequency of the current node, and if a maximum number of VIM lines is not exceeded.

16. A method to statically determine liveness of indirect very long instruction word (VLIW) instructions comprising the steps of:

30 determining a control flow graph which includes nodes representing basic program blocks, and edges connecting the nodes which represent jumps and calls from one block to another block; and  
 determining a VLIW flow graph by solving VLIW flow equations.

17. The method of claim 16 wherein the VLIW flow equations comprise:  
 35  $I_n = U_n \cup (O_n - D_n)$ ; and

$$O_n = \cup_{s \text{ in } \text{succ}(n)} I_s;$$

where "n" is a given node,  $I_n$  is a set of live-in VLIWs at node "n",  $O_n$  is a set of live-out VLIWs at node "n",  $U_n$  is a set of VLIWs that are used in "n",  $D_n$  is a set of VLIWs that are defined in "n", the live-out VLIWs of node "n" are all the VLIWs that belong to live-in sets of successor nodes of "n", and the notation  $\cup_{s \text{ in } \text{succ}(n)} I_s$  denotes the union of all sets  $I_s$  where s is a successor node to node n.

5 18. A method to statically determine interference of indirect very long instruction word (VLIW) instructions comprising the steps of:

determining an interference graph comprising VLIW nodes in which every VLIW  
10 node of the interference graph corresponds to one VLIW instruction.

inserting an undirected edge into the interference graph between two VLIW nodes if  
the two VLIW instructions belong to a live-out set of the same node of the VLIW flow graph;  
and

coloring the VLIW graph nodes such that adjacent VLIW nodes are colored in  
15 different colors and each color corresponds to a different VIM line.

19. An apparatus for allocating indirect very long instruction word (VLIW)  
instruction memory (VIM) comprising:

means for identifying a plurality of VLIW instructions in an input source program;

means for determining a lifetime of each of said plurality of VLIW instructions; and

20 means for allocating VIM based on the lifetime of each of said plurality of VLIW  
instructions.

20. The apparatus of claim 19 wherein the means for determining the lifetime of  
each of said plurality of VLIW instructions further comprises:

means for determining a control flow graph for the input source program containing

25 said plurality of VLIW instructions;

means for determining a VLIW flow graph for said plurality of VLIW instructions;

and

means for determining VLIW interference.

21. The apparatus of claim 20 wherein the means for determining the VLIW flow  
30 graph further comprises:

means for solving VLIW flow equations.

22. The apparatus of claim 20 wherein the control flow graph includes:

a plurality of nodes which correspond to basic blocks of the VLIW instructions; and  
a plurality of edges, wherein each edge corresponds to a jump or a call from a given

35 basic block to another basic block.

23. The apparatus of claim 22 wherein the flow control graph at each of said plurality of nodes includes:

- at least one VLIW instruction defined by the node; and
- at least one VLIW instruction used by the node.

5 24. The apparatus of claim 23 further comprising:

means for determining live-in sets and live-out sets for each of said plurality of nodes.

25. The apparatus of claim 24 wherein the VLIW flow graph comprises the control flow graph and the live-in sets and live-out sets for each of said plurality of nodes.

10 26. The apparatus of claim 25 wherein the means for allocating VIM further includes:

means for determining an interference graph in which every node of the interference graph corresponds to one of said plurality of VLIW instructions.

27. The apparatus of claim 26 wherein the VIM comprises a plurality of VIM lines, and the means for determining an interference graph further comprises:

15 means for inserting an undirected edge into the interference graph between two VLIW nodes if the two VLIW instructions belong to a live-out set of the same node of the VLIW flow graph; and

means for coloring the interference graph nodes such that adjacent interference nodes are colored in different colors and each color corresponds to a different VIM line.

20 28. The apparatus of claim 19 wherein the lifetime of a VLIW instruction is a time interval extending from when said VLIW is defined by a load VLIW instruction to when said VLIW is last executed by an execute VLIW instruction.

29. The apparatus of claim 19 further comprising:

means for merging two non-overlapping VLIWs to share a common VIM line only 25 when colorability of a resulting VLIW interference graph does not worsen as a result of said merging.

30. The apparatus of claim 19 further comprising:

means for utilizing a coalescing heuristic to reduce VIM requirements of a program.

31. The apparatus of claim 30 wherein said means for utilizing a coalescing heuristic produces a coalesced VIM address holding two or more of said plurality of VLIW 30 instructions.

32. The apparatus of claim 19 further comprising:

means for shortening the life of a particular VLIW by placing an initialization LV statement adjacently prior to the use of its corresponding XV statement.

33. An apparatus for optimizing the execution time of a user program by reducing redundant loads of very long instruction word (VLIW) instruction memory (VIM) comprising:

means for selecting a load VIM (LV) instruction in a current node; and

5 means for placing the LV instruction in a new node which is closer to a program start node if an execution frequency of the new node is lower than an execution frequency of the current node, and if a maximum number of VIM lines is not exceeded.

34. An apparatus for statically determining liveness of indirect very long instruction word (VLIW) instructions comprising:

10 means for determining a control flow graph which includes nodes representing basic program blocks, and edges connecting the nodes which represent jumps and calls from one block to another block; and

means for determining a VLIW flow graph by solving VLIW flow equations.

35. The apparatus of claim 34 wherein the VLIW flow equations comprise:

15  $I_n = U_n \cup (O_n - D_n)$ ; and

$O_n = \cup_{s \text{ in } \text{succ}(n)} I_s$ ;

where "n" is a given node,  $I_n$  is a set of live-in VLIWs at node "n",  $O_n$  is a set of live-out VLIWs at node "n",  $U_n$  is a set of VLIWs that are used in "n",  $D_n$  is a set of VLIWs that are defined in "n", the live-out VLIWs of node "n" are all the VLIWs that belong to live-in sets of successor nodes of "n", and the notation  $\cup_{s \text{ in } \text{succ}(n)} I_s$  denotes the union of all sets  $I_s$  where s is a successor node to node n.

36. An apparatus statically determining interference of indirect very long instruction word (VLIW) instructions comprising:

25 means for determining an interference graph comprising VLIW nodes in which every VLIW node of the interference graph corresponds to one VLIW instruction.

means for inserting an undirected edge into the interference graph between two VLIW nodes if the two VLIW instructions belong to a live-out set of the same node of the VLIW flow graph; and

30 means for coloring the VLIW graph nodes such that adjacent VLIW nodes are colored in different colors and each color corresponds to a different VIM line.